SUPPLEMENTARY IRRIGATION OF PASTURES IN HUMID AREAS

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1. SUMMARY

Some economic and technical aspects of part-farm or "supplementary" irrigation are discussed with particular reference to dairying in warm areas such as the North Coast of New South Wales. Some physiological limitations to plant and animal responses to irrigation are also discussed.

There is need for research into the influence of variations in rainfall throughout the year on production uncertainty and the physical input-output relationships between irrigation water and animal products over time under farm conditions and in comparison with alternative measures such as the feeding of purchased grain.

Supplementary irrigation may reduce income uncertainty but price fluctuations still contribute to income variation. Irrigated pastures are not effective in providing supplementary fodder to reduce production uncertainty equally at all times of the year and preoccupation with the production stabilising aspects of irrigation may lead to excessively high costs and imperfect realisation of production potential.

There are possibilities of benefiting from complementary relationships by diverting some resources from dry-land farming to irrigated production, but these may be overemphasised especially in current publicity and

farmers' expectations concerning irrigation. It does seem that the greatest net revenue increases are likely to be achieved by concentration on part-farm irrigation designed to exploit possible complementary relationships but alternative measures may be more profitable in this particular case.

It is contended that a most important criterion of economic efficiency in supplementary irrigation enterprises is often overlooked. It is not a sufficient condition that returns exceed costs and that real or subjective production uncertainty be reduced: the opportunity costs of achieving similar results by other means, which are believed to exist, must be also considered.

The magnitude of likely returns from part-farm irrigation is estimated. It is believed that these are not high on a per acre basis and that the long run cost and revenue curves for irrigation projects manifest substantial returns to scale. Hence irrigation of small areas, to which many farmers are restricted, if it does not indeed represent irrational production, is liable to show poor rates of return to scarce inputs, particularly capital and managerial effort.

2. INTRODUCTION

To production economists the term supplementary connotes an enterprise which can be added to an existing one so that with resources constant there is neither a gain nor sacrifice in the product(s) of the pre-existing enterprise. In every-day use the word has a wider meaning.

Under semi-arid or arid conditions part-farm irrigation may permit the undertaking of a new enterprise such as fat lamb production where there is subjective certainty that weather conditions will not otherwise permit such a venture. This is not the same proposition as endeavouring, by "supplementary" irrigation, to stabilise or render more profitable a venture which normal weather conditions permit to be undertaken albeit at less than maximum theoretically attainable levels of production.

Rutherford has used the term "integrated" applied to part-farm irrigation used as a measure to exploit complementary and supplementary relationships and also reduce yield uncertainty in semi-arid areas.[1] However "supplementary" part-farm irrigation of pastures (and fodder crops) is sometimes undertaken with the objectives of both reducing yield uncertainty and providing forage at times of relatively *certain* shortage. Often the relative proportions between the various goods produced by the farm firm are not altered in consequence. This is the situation on dairy farms on the North Coast of New South Wales producing milk for factory processing.

It is common to assume that with such part-irrigated enterprises there will be a complementary relationship between the irrigated and non-irrigated activities on the farm.[2] In the case of dairy cattle these may be

[1] John Rutherford, "Integration of Irrigation and Dryland Farming in the Southern Murray Basin", this *Review*, Vol, 26, No. 4 (December, 1958).

[2] Enterprises are complementary when the allocation of an increased proportion of a constant resource supply to one increases output of the other.

expected to arise from the fact that poor nutrition of the beast at one period can have deleterious effects on production extending into a subsequent period when feed supplies may be superabundant. The more important of these effects are discussed in later sections.

The degree of complementarity can be expected to decrease as the relative proportion of irrigation to non-irrigation activities is increased. In the limit with full-farm irrigation versus no irrigation the relationship is competitive.

In recent years in this State, so called supplementary irrigation has been increasingly advocated by various individuals and institutions with special emphasis on the technical possibilities it affords for increasing gross income. There have been decided advances in equipment design and techniques of irrigation. These new techniques have had the common result of requiring more expensive equipment and irrigation has become a more intensively capital-using process. Such a trend is not of itself desirable in industries such as dairying where produce is exported and increased output tends to lower average returns. In these industries lower unit costs are especially desirable, and commonly capital is scarce.

Krimgold[3] refers to the insignificant proportion of supplemental irrigated to total land used in the United States.[4] Many New South Wales farmers do not irrigate although part-farm irrigation would be possible on the property.

The operators of many farms with irrigation potential not developed must surely be aware of its existence. A possible reason why they are not using irrigation is that they value resources differently from their advisers, or, understandably when input-output information from supervised experiments by independent authorities is conspicuously lacking, they may be unconvinced that costs can be recovered.[5]

Another extremely important reason why irrigation may not be undertaken when it is technically feasible is that there are alternatives and that these, where practised, may allow more efficient use of resources.

The question of opportunity costs of irrigation seems to have been little discussed although the use of criteria enumerated by Lewis suggests that even some public schemes do not represent the most economically efficient allocation of national resources.[6]

Where irrigated and unirrigated enterprises are alternative or competitive, marginal productivity of resources allocated to either may be assessed with reasonable accuracy. Where part of the return from irrigation is expected

[3] D. B. Krimgold, "Economic Feasibility of Supplemental Irrigation", *Agricultural Engineering*, Vol. 35 (1954), pp. 22-27.

[4] Excluding Florida citrus, 250,000 out of 122,000,000 acres of harvested cropland east of the Mississippi.

[5] It is probably unwarranted cynicism to suggest that the drastic precautions taken to secure advances for the purchase of irrigation equipment by some lending authorities indicate a similar state of doubt!

[6] J. N. Lewis, "Criteria for Evaluation of Development Projects", *Quarterly Review of Agricultural Economics*, Vol. VIII, No. 3 (July, 1955).

to arise from incompletely defined complementarity with other enterprises the task of quantifying the opportunity costs and probable returns of irrigation is rendered more difficult.

In the more humid areas of New South Wales, predominantly devoted to the production of milk for processing, virtually no investigation of input-output relationships under irrigation has been made but the risk of over-estimating the complementary relationships seems real. On the other hand, alternatives do exist ; some offer equivalent opportunities to benefit from complementary relationships, and their relative costs can be determined, at least for specific properties.

3. PRODUCTION UNCERTAINTY IN THE NORTHERN DAIRY AREAS

On the North Coast of New South Wales dairy production fluctuates fairly widely from season to season although even with price stabilisation, based on Australia-wide production costs and part only of exports of butter and cheese, price fluctuations still contribute to income uncertainty. Production uncertainty is probably dominated by rainfall variability although, on the individual farm, other factors such as a tendency for cyclical variation in the incidence of a number of diseases may be important.

Although fluctuations in production follow variations in rainfall received, particularly variations within certain critical periods of the year, it does not seem that the two vary in direct proportion ; indeed technically there is no reason to believe they should. Table I provides statistics for factory receivals of cream and rainfall for an area near Kempsey over a period of seven years, assumed to be from relatively constant numbers of cattle. It will be seen that production varied between extreme years by approximately ± 30 per cent about the seven-year average, whereas rainfall for the whole year and for various stages of the assumed lactation pattern varied in some cases by three times this amount. The statistics for 1950-51 and 1956-57 illustrate this comparison.

TABLE I

Cream Received and Rainfall Registered Over Seven Successive Years at a Butter Factory near Kempsey, New South Wales North Coast

Year	Cream	July-Nov.	Dec.-March	April-June	July-Nov.	Dec.-March	April-June	Total Rainfall
	Full Year	Cream	Cream	Cream	Rainfall	Rainfall	Rainfall	
	'000 lb. Commercial Butter				Inches			
1950-51	580	215	293	72	30·15	34·61	9·35	74·11
1951-52	325	111	95	119	2·88	16·15	5·73	24·76
1952-53	554	190	228	136	23·90	33·19	3·72	60·81
1953-54	402	133	158	111	4·46	27·20	6·60	38·26
1954-55	631	202	313	116	21·64	27·21	12·42	61·27
1955-56	664	228	325	111	7·36	56·47	11·47	75·30
1956-57	488	163	203	122	3·81	16·26	0·68	20·75
Means	520	177	230	114	13·46	30·16	7·14	50·75
Mean as per cent Annual Mean	100	34	44	22	26·5	59·4	14·1	100·0

Table II shows the variation in receivals at two factories operated by the Norco Co-operative Company Limited during the period 1932-33 to 1946-47, which illustrate a similar range between maximum and minimum production for the fifteen-year period.[7]

TABLE II

Amounts of Cream Received by Two Far North Coast Factories for the Years 1932-33 *to* 1946-47

Year	Byron Bay Factory		Kyogle Factory	
	Cream Received	Variations from Previous Year	Cream Received	Variations from Previous Year
	'000 lb. Commercial Butter			
1932-33 ..	4,332	..	2,323	..
1933-34 ..	4,810	478	2,878	555
1934-35 ..	4,656	154	2,808	70
1935-36 ..	5,671	1,015	2,548	260
1936-37 ..	3,641	2,030	2,191	357
1937-38 ..	3,720	79	2,617	426
1938-39 ..	3,235	485	2,250	367
1939-40 ..	3,280	55	2,792	542
1940-41 ..	3,408	128	2,551	241
1941-42 ..	2,597	811	2,916	365
1942-43 ..	3,253	656	3,183	267
1943-44 ..	2,773	480	3,223	40
1944-45 ..	2,374	399	2,832	391
1945-46 ..	2,401	27	2,937	105
1946-47 ..	1,816	585	2,232	705

If we assume that average production per cow in these three areas was of the order of 150 lb. commercial butter per annum (a figure in excess of present-day averages) we can arrive at an estimate of $\pm$ 40 lb. commercial butter per cow as the order of extremes of variation in production per cow in good and bad years for Byron Bay with 60 inches approximate rainfall average and $\pm$ 25 lb. commercial butter per cow for Kyogle (40 inches per annum approximately).

A general pattern for receivals of cream at coastal factories appears to approximate:

One-third received in Spring (July-November).

One-half received in Summer (December-March).

One-sixth received in Autumn (April-June).

The experience with varying rainfall patterns such as those at Kempsey in 1952-53, 1955-56 and 1956-57 tends to support the assumption that supplementing pasturage grown with normal rain, by irrigation or otherwise, in any one of the three periods of the year will not remove all production uncertainty. It might be tentatively postulated that more of the variation in annual yields might be removed by supplementary feeding at some times

[7] Comparisons are almost certainly complicated by the presence of a downward trend with time.

of the year in preference to others, with the weight of field and experimental evidence favouring Spring as the time when complementarity between suplementary feeding and the grazing of non-irrigated pastures is most likely.[8]

4. PHYSIOLOGICAL CONSIDERATIONS LIMITING RETURNS FROM IRRIGATION

Water Input—Feed Output Relationships in Pasture Irrigation

Numerous measurements of water input—crop output or transpiration ratios for crops and pasture plants have been made. These indicate a range from about 350 parts of water transpired for one part dry matter produced by such crops as sorghum and maize through an average of about 800 to 1 for pasture legumes such as lucerne up to 1,400 to 1 (in the case of Ohio "meadow" pastures in the United States). In the case of lucerne the coefficients have varied from 600 to 1,000 to 1 at the one site from year to year.[9, 10] Reports of several years' investigations at the Werribee State Research Farm, Victoria, suggest transpiration coefficients of 700 to 900 to 1 for irrigated lucerne and up to 1,100 to 1 for pastures of Perennial Rye Grass, Cocksfoot, White and Subterranean clovers.[11] A recent New Zealand report[12] indicates that with spray irrigation and an irrigation efficiency around 90 per cent an average application of 12 acre-inches of water was required per ton of pasture hay produced from Clover-rye grass pastures over a five-year period.[13] This represents a conversion ratio requiring 1,300 parts of water at the pump per one part dry matter produced.

If we estimate the average food value of such material at 40-50 food units per 100 lb. dry matter and apply conversion ratios obtained in stall feeding experiments this corresponds to a potential added production of about 140 lb. to 160 lb. butterfat per acre-foot of irrigation water used to produce pastures for dairy cows.[14]

It is common practice for water usage to be restricted in the coastal humid region to winter growing pastures. Under such conditions *average* water usage is likely to be 12 to 16 inches per year. On this assumption the

[8] Since the above was written, coefficients of correlation between monthly rainfall and annual production data on which Table I is based have been calculated. These are non-significant and in some cases negative for rainfall in the May and June preceding each financial year and for July, August, October, December, February, April, May and June. There is a highly significant correlation between August production and annual production. Although not conclusive these results do not contradict the hypothesis above.

[9] K. H. W. Klages, *Ecological Crop Geography* (New York: Macmillan, 1947), p. 177.

[10] D. Hughes *et. al., Crop Production Principles and Practices* (New York: Macmillan, 1957), p. 9.

[11] State Research Farm Werribee, *Guide Book*, 1958-59 (Melbourne: Department of Agriculture), p. 49 (Table I).

[12] B.D. van 't Woudt, "Recent Advances in the Irrigation of Pastures in New Zealand", *World Crops*, Vol. 10, No. 6 (June, 1958).

[13] Irrigation efficiency is the proportion of a given water supply reaching the effective root zone of the crop.

[14] E. T. Halnan and F. H. Garner, *The Principles and Practice of Feeding Farm Animals* (London: Longmans, Green & Co., 1953).

theoretical limit to average production attributable to irrigation would be 140 to 220 lb. of butterfat per acre per annum assuming the same efficiencies as in experimental determinations of transpiration coefficients and feed conversion rates.

The following section compares results obtained from actual irrigation installations with the assumed upper limits based on the experimental determination of water-foodstuff conversion rates.

Irrigation Inputs and Animal Outputs

Very limited observations of actual production of animal products from irrigated pastures seem to have been made. Geddes[15] has reported that 45 acres of irrigated pasture at Badgery's Creek in 1956 returned 701 gallons of milk to the acre, equivalent to, say, 300 lb. butterfat. Werribee[16] data show an average liveweight gain by sheep on irrigated pasture as the sole source of feed of 762 lb. per acre over a seven-year period on 2½ acre plots with total moisture receivals of about 36 inches per annum. This result is very similar to that achieved by Geddes since reference to standard feeding tables[17] discloses that the feed inputs for 1 lb. liveweight gain and 1 gallon of milk produced are generally considered to be approximately equal. Jones and Wakeland at Illinois, recorded an average liveweight gain by beef cattle of 347 lb. from irrigated and 236 lb. from unirrigated pastures over a five-year period.[18] The liveweight gains from irrigated pastures varied from 140 to 530 lb. per acre from year to year. Average water application was 13.0 inches and average rainfall 21.0 inches. These pastures were grazed in Summer only. The year to year variations in output are of interest.

These results were achieved under conditions not typical of the "average" farm. There is some justification for considering the Australian figures to be near ceiling production with present standards of management. In particular they may not be duplicated in many high rainfall areas of New South Wales where some pasture legumes are difficult to establish and maintain and where excessive precipitation is believed to significantly limit production at some times. It is fairly common to experience a drop in butterfat production during excessively wet periods in Summer in North Coastal New South Wales. The writer has observed this without knowing the precise cause. It has been suggested that cattle are forced to ingest large amounts of water, which "dilutes" their feed and limits dry matter uptake. Certainly pasture growth may be checked or plants killed by waterlogging for prolonged periods. Part of the cause of observed short-term depression in butterfat yield may be a "psychological" response by the cattle to conditions which can be most depressing to man at least.

In a relatively dry Spring and Summer at Murwillumbah in 1953-54 the author made observations and estimates of increased production from irrigated pastures on three properties which appeared to be managed at

[15] H. J. Geddes, "The Business Side of Sprinkler Irrigation", Part 9, *The Milk Board Journal,* Vol. 10, No. 2 (February, 1959), p. 29.

[16] State Research Farm Werribee, *op. cit.*

[17] Halnan and Garner, *op. cit.*

[18] B. A. Jones and H. L. Wakeland, "Supplemental Irrigation of Pastures", *Agricultural Engineering,* Vol. 36, No. 3 (March, 1955), p. 181.

average standard or somewhat better.[19] The farmers concerned were irrigating areas of 5-8 acres and their estimates of increased production due to irrigation (about 18 inches water applied) were of the order of 180 lb. additional butterfat per acre irrigated—about 22lb. per cow. These estimates were based on experience prior to irrigation, results obtained by neighbours without irrigation in 1953-54 and, in one case, by the effect on production when the water supply was exhausted.

It is of interest that in the following year, 1954-55, the season was relatively wet and the irrigation plants were little used. This serves to emphasise the extremes in response to irrigation which may be expected from year to year.

On the properties under discussion the land irrigated had been sown to pastures at substantial extra cost for seed and fertiliser. It was assessed on the basis of past performance as capable of producing on average 70-80 lb. butterfat per acre per annum from naturalised pastures of dominantly summer growing species, not fertilised. We might then assume that in practice average farmers in North Coast areas may achieve production of the order of 250 lb. butterfat per acre from irrigated pastures in a year with a dry Spring (pastures showed almost continuous water stress from August, 1953, until the last week of January, 1954; rainfall for the seven months ending December 31, 1953, was 961 points below the average of 2,567 points), but that not all of this production is attributable to the use of irrigation water alone.

Particularly on the upper reaches of the New South Wales humid coastal rivers, the better land on the farm is normally close to the water supply and is of the most favourable slope, fertility and textural characteristics for irrigation. Assuming that production from irrigated pastures was at the level of 250 lb. per acre in all years and deducting the average production without irrigation of, say, 80 lb. butterfat per acre per annum we arrive at a figure of approximately 170 lb. extra butterfat per acre as the likely output from irrigation. However, this figure must be discounted because of three factors.

(i) In very wet years excess water may reduce plant growth or at least reduce the butterfat produced per acre.

(ii) In good years, when perhaps the application of about six inches of water in Spring may be called for, it has been observed that farmers tend not to use their irrigation plants, at least to the technically optimal degree. This is not necessarily due to any inherent disability of the irrigation plant. It is, however, difficult to judge just when irrigation is needed under such circumstances and the farmer may well have equally pressing calls on his time even if he were to judge accurately.

(iii) There is an observed tendency for a reduction in the supplementary relationship between supplemental and non-irrigated sources of feed due to

[19] All strip grazed and mowed pastures and were successful in regulating calving dates at recommended times. One conducted his own Babcock tests, one subscribed to an overseas journal, etc., characteristics commonly shown by survey data to be associated with management of better than average efficiency (for example, *vide* F. H. Gruen, "Incomes of Dairy Farmers in the Richmond-Tweed Region", this *Review*, Vol. 23, No. 3 (September, 1955)).

idiosyncracies of the grazing animal which would tend to reduce the benefits from supplemental irrigation in years of less than extreme drought.[20]

In the absence of any concrete evidence of the absolute magnitude of such effects it is possible to do no more than hazard the guess that under commercial farm conditions average increments to production from grazing animals through supplemental irrigation in humid areas such as Murwillumbah would be of the order of 140 lb. butterfat per acre per annum or its equivalent.

It will be seen, to conclude discussion of this aspect of input-output relationships between irrigation and the animal product butterfat, that, under conditions of moderately abundant, if uncertain, rain—a condition typical of the humid coastal areas—there is likely to be a relatively small increase in *total* farm production attributable to irrigation water as such, and both the limited experimental data and field observations available and quoted here are in fairly good agreement at a figure well below 200 lb. butterfat per acre irrigated per annum, certainly much less than farmers are currently led, by inference at least, to expect.

Feed Conversion Ratios in "Supplementary" Feeding

There is a growing body of evidence that supplementing the diet of animals grazing poor pastures with concentrates, silage or specially grown forages fails to a substantial degree in proportionately increasing milk or meat production. Some of this evidence has been reviewed by McClymont.[21] A report by Wallace[22] indicates the rapidity with which stock can graze given limited access to relatively palatable pastures such as those produced under irrigation might be when unirrigated pastures were suffering from drought effects.

Most stockmen have observed that stock allowed limited access to palatable feed at regular times will often stand waiting for long periods beforehand. It would seem that there is a disinclination to forage as diligently on unattractive feed when something better is expected to be offered.

The effects of such behaviour are probably unquantifiable under field conditions, but it seems evident that considering a farm of, say, 100 acres capable of producing 8,000 lb. butterfat in a given season, the installation of a plant to irrigate 20 acres of pasture, capable of producing 80 lb. butterfat without, or 250 lb. butterfat with, irrigation if they provide the sole feed for dairy cattle, will not necessarily result in the addition of (250-80) 20 or the 3,400 lb. butterfat which might be expected as an increment to farm output if the cattle co-operated in revenue maximisation.

Complementary Effects and Supplementary Feeding

In dairy farming in New South Wales factory supply areas, complementary and supplementary relationships between the main enterprise and irrigation depend in particular on the observed response when cattle are "steamed up", i.e. maintained in a high plane of nutrition for approximately

[20] This point is discussed in detail in the section headed "Feed Conversion Ratios in 'Supplementary' Feeding", p. 247.

[21] G. L. McClymont, "Response of Stock to Supplementary Feeding on Pastures", *Proceedings of the Australian Society of Animal Production*, Vol. 1 (1956), p. 63.

[22] L. R. Wallace, "Making the Best Use of Winter Grass", *Dairy Farming Annual*, Massey Agricultural College (1958).

two months before calving. A second characteristic of lactating dairy cattle, a decreasing ability to regain high levels of production when subjected to temporary deprivation of feed, is considered to be of less importance—especially in the humid areas of Northern New South Wales—for two reasons.

First, the characteristic is of most importance the nearer the cattle approach the end of their lactation ; in the first few months after calving cattle can withstand a temporary setback. Hence the opportunity for long sustained benefit from diet supplementation decreases after calving.[23]

Second, the irrigation of Summer pastures requires provision to meet short-term drought of virtually unpredictable time of incidence, at a period of high temperatures when the management of irrigated areas will be at maximum complexity and cattle commonly fall in production apparently for reasons other than deficient rainfall—even because of excessive rainfall—or because grasses are declining in food value.

Flux[24] reports an investigation using identical twin calves, one set was allowed to lose bodyweight to the extent of 70 lb. in the ten weeks prior to calving, the other was "steamed up" (receiving additional feed) so that weight at calving was equal to their weight ten weeks earlier. Both groups subsequently had free access to good pasture.

After calving, the under-fed group slowly regained bodyweight, finally catching up with the better-fed group, which latter produced more butterfat over the whole lactation. However the amount of extra butterfat produced was identical in energy equivalence to the bodyweight gain made by the under-fed lower producing identical twin sisters.

Evidence of this character tends to emphasise the competitive relationship between factor inputs used in irrigation as compared with other uses. Irrigation is principally a method of producing nutrients in excess of those afforded by natural rainfall. In many cases this feed will be required principally for the digestible energy it provides and not for any indefinite property such as "greenness" or "succulence", and this energy could be equally well supplied by hay or grain, if necessary with nitrogen supplementation.

It was postulated earlier that an average increase in production of about 40 lb. butterfat per cow would be required to achieve consistently the levels now secured in the best years. If this increase could be achieved solely by "steaming up" and better nutrition during the early part of the lactation the additional feed required would be comparable with that required by Flux's cattle to avoid the loss of 70 lb. bodyweight. (Coincidentally the experimental animals used by Flux produced at rates approximately those to be achieved in the hypothetical situation above.)

If we make a second assumption that about half the variation in annual production is due to differences in feeding early in the lactation (and the author has some unpublished evidence that this may be a minimum figure

[23] It is worth recalling that much data on feeding relates to cattle producing at far higher levels than the majority in New South Wales herds.

[24] D. S. Flux, *The Effect of Undernutrition Before Calving on the Quantity and Composition of Milk Produced by Two-Year-Old Heifers* (New Zealand Dairy Research Institute, Pub. No. 234, 1950).

on the North Coast of New South Wales) it is not improbable that concentrate feeding could substitute for irrigation of pastures to reduce production uncertainty *pari passu* on the basis of starch equivalent supplied.

In the simple case that energy content of the feed be the limiting factor, rather than protein content, 700 lb. of starch equivalent supplied as, say, sorghum grain, equivalent to 140 lb. butterfat, could substitute for an acre-foot of water.

Seven hundred pound starch equivalent as sorghum grain could be purchased in Murwillumbah on June 1, 1959, for approximately £8 10s. 0d. at the farm gate. In recent years the cost of 1,000 lb. of sorghum (700 lb. starch equivalent) has been less than £10 which is less than the cost of producing an equivalent quantity of starch equivalent by applying an acre-foot of water in most circumstances.[25]

If forage is required to be produced by irrigation in July-August, which is not improbable, farmers may well be dependent on annual crops such as vetch or oats. This will amplify the expense and difficulty of irrigated fodder production which is elsewhere discussed predominantly with reference to established perennial pastures.

The feeding of grain to cattle probably requires less labour and less skill than does irrigation. It would seem that the main requirements are an ability to judge trends in bodily condition of pregnant animals and to weigh or measure a ration in the bail at daily or less frequent intervals. Augmenting the diet of cattle with sorghum grain may be expected to depress their intake of pasture to which they are accustomed, but probably not to the same extent as limited access to superior forage mentioned earlier.[26]

There is little capital outlay required to feed grain; and depreciation on irrigation plant, which is considerable even in years when it is little used, is eliminated.

It is not denied that there are problems attached to feeding dry dairy cattle. However, these are offset in part by the advantage gained from handling young heifers before calving. It is possible too that feeding at two or three-day intervals would be quite adequate.

5. THE CASH AND OPPORUNITY COSTS OF IRRIGATION

Irrigation Costs and Economies of Scale

The cash costs of irrigation in Australia have been estimated from actual installations in recent years by Geddes,[27] Lowndes,[28] and Waring[29] among others.

[25] Generally estimated to be between £8 8s. 0d. and £15 0s. 0d.

[26] L. R. Wallace, "Concentrate Feeding of Dairy Cattle", *Proceedings of the Ruakura Farmers' Conference Week* (Wellington: Department of Agriculture, 1957), p. 166.

[27] Geddes, *op. cit.*

[28] A. G. Lowndes, "The Farm Economics of Spray Irrigation", *The Living Earth*, Vol. 4, No. 2 (December, 1958), p. 23.

[29] E. J. Waring, "The Economics of Irrigation", Proceedings of Residential Extension School, University of New England, February, 1959. (In Press.)

For installations of reasonable size, say, 12 to 14 acres, the estimates agree broadly in a range of from about 14s. 0d. to 25s. 0d. per acre-inch of water reaching the root zone.

At a given location the largest single source of variation in delivered water cost for an installation of a particular size is likely to be the cost of labour. About a half to one man-hour is required per acre-inch of water applied. In typical supplemental projects of, say, 8-10 acres, on a humid-area dairy farm no additional labour may be required so that labour costs need not necessarily be charged against the project.

On the other hand the capital cost of small installations is very high, so that average costs decrease sharply in the range of about 1-10 acres. Typically an installation to irrigate 1 acre might cost £300, to irrigate 10 acres £750, and to irrigate 15 acres £850. Depreciation, interest and maintenance amount to an estimated $11\frac{1}{2}$ per cent of installation costs.[30] For very small installations these costs alone can exceed returns, leading to uneconomic production in the long run.

For installations of about 40 acres the costs of plant, fuel and labour are approximately equal and individually slightly exceed the fourth component of costs, additional fertiliser, mowing, special seeds and similar costs directly incurred because of the irrigation enterprise.

If we assume that the first 15-20 acres on a family farm can be watered using family labour at no opportunity cost, and that thereafter labour must be hired and that one man can water 40 acres, the typical *long run* cost curve when deciding the size of an irrigation project would be somewhat as shown in Fig. 1. This curve is ratchet shaped and shows an area of

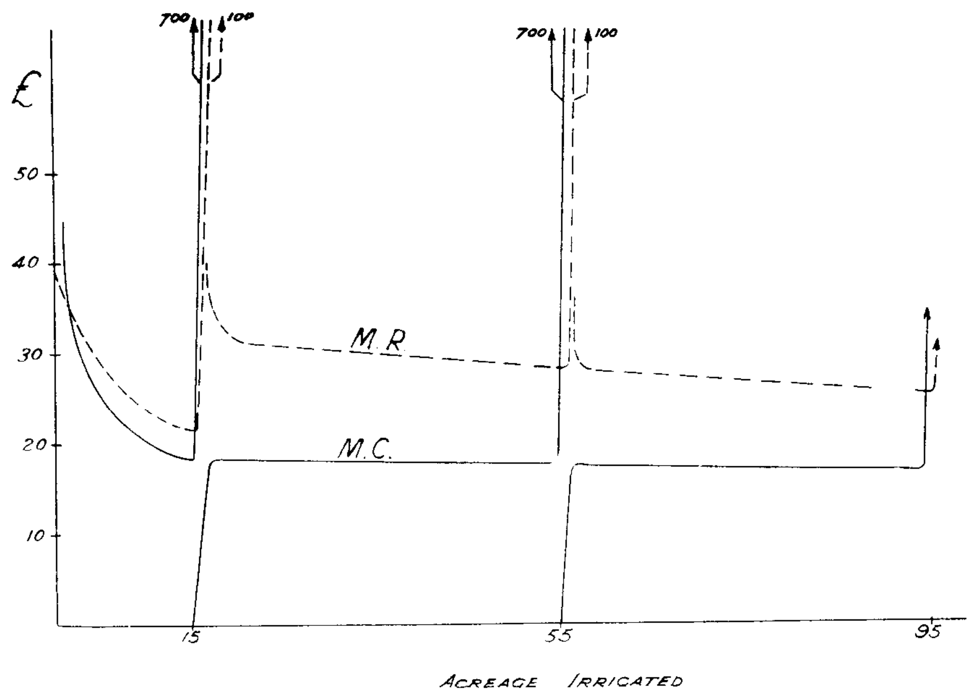

Fig. 1. .Postulated Long-run Marginal Cost and Revenue Curves for Spray Irrigation Plants

[30] Waring, *op. cit.*

irrational production for small acreages and thereafter within given ranges of plant size an optimal size corresponding with the area which can be handled by the needed minimum labour force.

It is again emphasised that this is the long run cost-curve facing the beginning irrigator when no fixed costs have been incurred.

The marginal revenue curve is assumed to show decreasing returns to a given labour force as more and more acres are worked up to the attainable maximum. Decreasing returns are also possible as projects increase in size because once the "feed-year gap" has been filled, or as production uncertainty due to rainfall variability is progressively reduced the production possibilities of irrigation change—the project tends to become competitive.

The Opportunity Costs of Irrigation

Crop and pasture production under irrigation generally requires higher standards of management than dryland production and high labour inputs per acre.

The technical reasons for concentration on irrigation of winter-spring crops and pastures in contrast to the naturalised summer-growing species in the more humid coastal regions at least have been suggested. Thus, a prerequisite of irrigation is the establishment of such winter-growing crops and pastures, frequently with considerable difficulty and non-permanent results, besides additional labour and capital inputs for mowing, weed control, fertiliser, rotational grazing, etc.

These measures, and higher standards of management, essential to achievement of input-output relationships as high as those postulated in earlier discussion, can be expected to increase returns from dairy cattle, even without irrigation.

In assessing the opportunity costs and likely returns from irrigation of cattle pastures then one is faced *a priori* with the task of:

(*a*) deciding what part of any added production is due to the application of water *per se* ;

(*b*) determining the opportunity cost of capital, labour and management inputs used in irrigation in alternative uses such as fodder conservation, purchase of feedstuffs or more land, veterinary services, etc., which are in many cases potentially high.

Some of the alternative enterprises listed in (*b*) of the preceding paragraph are less liable to uncertainty than is irrigation.

6. RISK, UNCERTAINTY AND REVENUE IN RELATION TO SUPPLEMENTARY IRRIGATION

Part-farm irrigation may be undertaken with either reduced production uncertainty or increased income as the main objective. Increased income, particularly if it is to be secured from additional stock, may be attended by increased income variation.

Irrigated production is in itself subject to uncertainty arising from factors such as the increased stock damage or management difficulties following prolonged rain on newly-irrigated pastures.

Drought Survival Feeding

The production of meat, and of milk in the long term, requires that stock be fed at above maintenance levels for most of the year. Assuming that this is generally achieved, which seems true of most humid areas, the following considerations are significant:

(i) Stock losses from severe drought in humid regions will be relatively few and infrequent.

(ii) The feeding of purchased grains or hay is a technically acceptable alternative to irrigation for survival feeding.

(iii) In severe drought the water supply may fail.

The high long-run overhead costs of irrigation, in association with the three factors mentioned above, tend to make the feeding of purchased or home-conserved fodder more economical for this purpose.

Irrigation to Meet Certain Feed Shortage

Where there is certainty that feed supplies will be limiting at one time of the year stocking rates will be adjusted to maximise returns from this limitational resource. The closer this period of feed shortage approximates to one of severe acute deficiency and the colder the weather in which it occurs, the less the possibility of augmenting feed supplies by irrigation due to the limitations imposed on food production by low temperatures and phasic development of plants.[31] In midwinter as much as 2 acres of irrigated pasture might be required to support an extra cow.

If we consider the extreme case of irrigation strictly in drought years only, with drought of (known) frequency of, say, one year in five, the annual return from an acre of irrigation in such use would be very low.

Irrigation with Variable Feed Supplies

Consideration of risk and uncertainty in dairy production due to varying feed supplies is greatly influenced by the high proportion of total feed (60 per cent at least) used by the cow for maintenance. This means that production may vary relatively more than feed supplies, since it is derived from a residual above maintenance requirements.

The results of Flux quoted earlier indicate a substitutability of feed inputs in time if cattle are to be limited in feed consumption throughout the year. Under such conditions his low plane of nutrition heifers would have provided no return on expenditure aimed at transferring feed supplies from the later to the precalving period of the experiment.

[31] There may, however, be counter possibilities of autumn production of "winter saved" pastures, here disregarded.

However, it is normal for feed in excess of the appetite of stock to be available for substantial periods of the year. Results from New Zealand[32] indicate that under such conditions it is possible to secure transformation ratios as high as 1 lb. butterfat produced per 3 lb. starch equivalent supplement fed over a short period (eight weeks) immediately after calving This contrasts with the usual ratio of about 1: 5 and is attributed by Wallace to the fact that the "lactation drive" of the cow is better maintained the more readily she is able to meet the heavy demands for food to increase bodyweight in the early stages of lactation.

The possibility of such a complementary relationship between supplements and pasturage *over the full lactation* adds to the potential profitability of irrigation but the fact that these supplements may be required over quite a short time favours the alternatives even more.

The question of whether irrigation is most profitably employed in carrying more stock or increasing production per head of existing cattle with some reduction in variation of output depends on whether uncertainty is continuous throughout the year or restricted to the useful growing season of a particular crop or pasture. Yield uncertainty at different times of the year in certain humid districts is at present being studied separately in an endeavour to evaluate the possibilities suggested. From a preliminary investigation it appears that a factor favouring the carrying of extra stock with irrigation in periods of uncertain feed supply is the occurrence of some years when feed supplies are greatly in excess of requirements during the period at which irrigation will be most effective.

7. CONCLUSION

It is apparent that not all "supplementary" irrigation enterprises conform with the production economists' connotation of the term because the resources used are frequently augmented as well as changed in form when part-farm irrigation is instituted. A change in managerial attitudes may be the reason for installing irrigation. Certainly new skills of a high order of complexity must be applied to operate an irrigation plant at maximum technical and economic efficiency.

On family farms capital and labour ("managerial skill") are commonly limiting resources. In some cases it may be easy to obtain credit for the purchase of irrigation plant and farmers choose to add to capital investment for this purpose and overlook alternative uses. But there is a likelihood of opportunity costs arising from the non use of such capital and labour in dryland production.

The addition to total revenue from each acre of irrigation is not great in absolute amount and small scale plants are relatively costly to operate. Thus if several good seasons follow the purchase of irrigation equipment, the short term cost of foregone alternatives may be quite high.

Alternatives to supplemental irrigation do exist. Feeding of grain could be at least as effective in reducing uncertainty at comparable cost. Purchase of land at ruling prices in many dairy districts (say 10s. 0d.

[32] Wallace, *op. cit.*

to 15s. 0d. per lb. butter potential) would not normally reduce production uncertainty significantly but would add to total production at comparable cost to irrigation, sometimes, almost certainly, at lower cost.

There is need for research on input-output relationships and a real need for recognition in every day discussion of irrigation economics of the fact that the sole criterion of economic efficiency is not that cash returns shall exceed cash costs.